

5/11/15
- 1 -09/830303
JC02 Rec'd PCT/PTO 25 APR 2001DESCRIPTION~~LINEAR INDUCTIVE TRANSDUCER~~

5

Technical Field

INS
BI

The present invention relates to a linear inductive transducer including electric windings with a primary winding and a pair of secondary windings, a magnetic core, for performing linear displacements relative to the electric windings, a pair of input terminals electrically connected to the primary winding and adapted for being electrically connected to a power supply unit, at least an output terminal electrically connected to the electric windings, the transducer being adapted for providing, through the output terminal, an electric signal indicative of the mutual position between the electric windings and the magnetic core.

The invention also relates to a linear inductive transducer including electric windings with a primary winding and a pair of secondary windings, a magnetic core, for performing linear displacements relative to the electric windings, a pair of input terminals electrically connected to the primary winding and adapted for being electrically connected to a power supply unit, and output terminals electrically connected to the electric windings, the transducer being adapted for providing, through at least one of the output terminals, an electric signal indicative of the mutual position between the electric windings and the magnetic core.

Background Art

Transducers with these characteristics, in particular of the Linear Variable Differential Transformer (LVDT) type have been known for a long time and utilized, among other things, in many measuring apparatuses for providing

electric signals indicative of the mutual position between mechanical parts. These transducers include a primary winding and a pair of secondary windings connected together in series opposition. The windings are wound on a substantially cylindrical bobbin at the interior of which a ferromagnetic core displaces along an axial direction. The primary winding is energized with a sinusoidal voltage and generates, at the ends of the secondary windings, induced voltages that vary as the axial position of the core changes. More specifically, the voltages induced in the secondary windings are equal and oppositely phased when the core is at an axially centered position. Thus, the total voltage at the free terminals of the secondary windings is null at said axially centered position, while its amplitude varies as the axial position of the core changes, and its phase changes in response to the sense of the axial displacement with respect to the centered position.

In U.S. Patent No. 4,386,467 there is disclosed a possible application of an LVDT in a comparator for checking a hole of a mechanical piece, in which the core and the transducer windings are respectively coupled to two mutually movable arms that carry feelers for touching diametrically opposite points of the hole.

Other types of inductive transducers are known as Half Bridge Transducers or HBT. These transducers include a pair of series connected windings, wound on a bobbin and energized with a sinusoidal voltage at the free ends thereof, and a ferromagnetic core axially movable within the bobbin. The output voltage is drawn at an intermediate point between the windings and its amplitude varies as the axial position of the core changes. The HBTs are broadly utilized in measuring devices, especially in simple devices like axial, or cartridge, heads, in consideration of the attributes of simplicity and inexpensiveness. Furthermore, unlike the LVDT transducers, the half bridge transducers have low output impedance values (e.g., 300 ohm as compared to 2000 ohm that represent a typical value for an LVDT),

thus the negative effects due to increased load impedance caused by the cable for the connection to the conditioning units are negligible. In fact, different cable lengths determine different load impedance values at the output of the transducer, and said load impedance in turn determines a variation in the amplitude of the output signal that increases the more the transducer output impedance is higher.

In a half bridge transducer the output impedance is relatively low since it is determined by the parallel of the impedances of the two windings, while it is definitely higher in a differential transformer transducer, where it is determined by the sum of the impedances of the two series connected secondary windings.

Another advantageous feature of the HBT in comparison with the LVDT, particularly in multiple applications in which the signals sent by a plurality of transducers have to be managed, is the possibility of utilizing -between each of the HBT and the conditioning unit- one electric connection wire less (three, as compared to four that are necessary for the differential transformer transducers) thereby simplifying the application.

A drawback of the HBTs is the poor sensitivity, i.e. the low ratio between the detected output signal variation and the associated core displacement. In a half bridge transducer, the sensitivity mainly depends on the geometric characteristics, more specifically on the ratio existing between the dimensions of the windings and those of the core, both generally imposed by the dimensions of the measuring device including the transducer. Hence, it is impossible to independently define the sensitivity and modify it for specific applications, for example in an application of a comparator as the one described in the formerly mentioned patent US-A-4,386,467. In fact, in this specific case, as there is an "arms ratio" (i.e., the ratio between the amount of displacement of the feelers and the amount of the associated mutual displacement between the

transducer's core and windings) that is known and generally differs from one, it can be advantageous to define the transducer sensitivity in order to take into account this known ratio, in this way simplifying the processings performed by the conditioning circuit.

Disclosure of Invention

An object of the present invention is to provide a linear inductive transducer that overcomes the disadvantages of the known transducers and, more specifically, enables to define its sensitivity regardless of the geometric characteristics, and none the less ensures a lower output impedance value and a lesser number of external electric connections with respect to the known differential transformer transducers.

This and other objects and advantages are achieved by a transducer according to claim 1.

A further object of the invention is to provide a linear inductive transducer that can present the functional characteristics of a differential transformer transducer, or a half bridge transducer, or a transducer of another type, by carrying out simple and rapid modifications.

This further object is achieved by a transducer according to claim 8.

Brief Description of the Drawings

The invention is now described in more detail with reference to the enclosed sheets of drawings, given by way of non limiting example, wherein:

figure 1 is a circuit diagram of an inductive transducer according to a preferred embodiment of the invention,

figures 2a, 2b and 2c are graphs that show the trend of some of the voltages at various points of the circuit

diagram of figure 1, taken at a plurality of mutual positions between the movable parts of the transducer,

figure 3 is a circuit diagram of an inductive transducer according to a different embodiment of the invention and a first possible configuration,

figure 4 is a circuit diagram of the transducer of figure 3, according to a second possible configuration, and

figure 5 is a circuit diagram of the transducer of figure 3, according to a third possible configuration.

10 The circuit of figure 1 schematically shows an inductive transducer **T** including first and second primary windings 1 and 3, first and second secondary windings 2 and 4, two input terminals 5 and 6 and an output terminal 7. A magnetic core 8 can translate, with respect to windings 1-4, in the $\pm X$ direction.

15 A conditioning, or power supply and processing, unit **C** includes two sinusoidal voltage generators 11 and 13, connected to ground (identified by reference number 12) and in phase opposition to input terminals 5 and 6, respectively, while signal processing means, connected to output terminal 7, are schematically shown with a load impedance 15.

A connection point 9 intermediate between primary windings 1 and 3 (that have the same number of turns **N1**) is 25 connected to an end of one (2) of the secondary windings 2 and 4, the latter being connected to each other in phase opposition and having the same number of turns **N2**.

The dots **F** in the figure stand to indicate the phases associated with the voltages across the different windings 1-4 and the voltage generators 11 and 13.

30 In an application in a comparator as the one shown in U.S. patent No. 4,386,467, core 8 and windings 1-4 are connected to the two movable arms carrying the feelers, respectively. The operation of the circuit shown in figure 1 is as follows.

35

The primary windings 1 and 3 are energized with sinusoidal power supply voltages $V_{a_{11}}$ and $V_{a_{13}}$, that are identical and in phase opposition, supplied by generators 11 and 13.

- 5 The voltage V_o at output terminal 7, or measuring signal, is equal to the sum of two components: voltage V_s , present -with respect to ground- at intermediate point 9 between primary windings 1 and 3, and voltage V_s' induced in the overall secondary windings 2 and 4:

$$V_o = V_s + V_s' \quad (1)$$

- 10 More particularly, the value of V_s , or unbalance voltage of the primary windings, is defined by

$$V_s = (V_1 - V_3)/2 \quad (2)$$

where V_1 and V_3 indicate the voltages, or potential drops, across the primary windings 1 and 3, respectively, while the value of V_s' , or unbalance voltage of the secondary windings, is defined by

$$V_s' = V_4 - V_2 \quad (3)$$

- 15 where V_4 and V_2 indicate the voltages induced in the secondary windings 4 and 2, respectively.

- When core 8 is at the central, symmetric position with respect to both the primary windings 1 and 3 and the secondary windings 2 and 4 shown in figure 1, both the
20 components of the measuring signal V_o become null because the voltages at the ends of each of the primary windings 1 and 3 and each of the secondary windings 2 and 4, respectively, have identical value:

$$V_1 = V_3 \quad (4)$$

$$V_2 = V_4 \quad (5)$$

Thus, in these conditions $V_o = 0$.

- 25 The displacement of core 8, in response, for example, to the mutual displacement of the movable arms of the comparator including the transducer according to the invention, produces a variation in the reluctance of the magnetic circuits of windings 1 and 3. The consequent
30 inductance variation of the two windings produces two different voltage values V_1 and V_3 and thus an unbalance voltage V_s other than zero, according to formula (2).

The displacement of core 8 also varies the mutual inductance between the primary windings altogether considered (1+3) and each of the secondary windings 2 and 4, differentially connected to each other. Therefore, because $V_2 \neq V_4$, unbalance voltage V_s' generated in the secondary windings differs from zero, according to formula (3).

The voltages V_2 and V_4 induced in the two secondary windings 2 and 4 by the overall primary winding 1+3 depend -at a specific position of core 8- on a coupling coefficient K . More particularly, making the simplified hypothesis that primary windings 1 and 3 are equal and symmetric with respect to each other, as well as the secondary windings 2 and 4, then

$$V_2 = K \cdot V_1 \quad (6)$$

$$V_4 = K \cdot V_3 \quad (7)$$

with

$$K = k \cdot n \quad (8)$$

where k varies depending on the transducer geometric features, and n is the turns ratio between secondary and primary windings: $n = N_2/N_1$.

The above hypothesis foresees the same k value in both the formulas (6) and (7) for the sake of simplification and making the substantial aspects of this invention clearer.

When the position of core 8 differs from the central symmetric one of figure 1, by substituting the formulas (2), (3), (6), (7) and (8) in (1), there results:

$$V_o = V_s (1 - 2 \cdot k \cdot N_2/N_1) \quad (9)$$

Thus, from formula (9) there results that output voltage V_o at terminal 7 has a value that, for displacements of core 8 of the same amount, varies among other things as the ratio of the turns varies $n = N_2/N_1$. As a consequence, contrary to what occurs in the known half bridge transducers, when the application requirements vary, the sensitivity can be set regardless of geometric considerations by choosing the appropriate turns ratio value n .

The figures 2a, 2b and 2c show the trend of the voltages hereinbefore mentioned in response to the various positions of core 8. More specifically, figure 2a refers to the situation shown in figure 1 (core 8 is in a central and symmetric position) while figures 2b and 2c refer to situations according to which core 8 is displaced along -X and +X, respectively.

The trends of output voltage V_o of figures 2b and 2c show that, as the position of core 8 changes, the amplitude of the formerly mentioned voltage V_o varies, while the phase indicates the sense (-X or +X) of displacement of core 8 with respect to the central position of figure 1.

From the foregoing description and the figure 1 illustration, it appears that transducer T is connected to conditioning unit C by means of three conductors ending at terminals 5, 6 and 7, two being necessary for the power supply and one for the transmission of output signal V_o .

Another advantage of the transducer shown in figure 1 with respect to the known differential transformer transducers consists in the possibility of obtaining limited output impedance values. In fact, while the impedance value is determined, even in the arrangement shown in figure 1, by the sum of the impedances of the two secondary windings 2 and 4, in this case it is possible to choose a small number of turns N_2 (and consequently low impedance values of the secondary windings 2 and 4) without causing -contrary to what occurs in the LVDTs- an unacceptable decrease in the transducer sensitivity. In fact, in the transducer according to the present invention, output signal V_o does not only depend on the transformer coupling, but, according to formula (1), it is the sum of two components. Thus, the choice of the appropriate turns ratio n (formula (9)) enables to achieve -in an extremely flexible way- the best possible balance among the required sensitivity and output impedance values.

According to an alternative to the herein illustrated and so far described embodiment, the primary windings 1 and 3

are energized with a single sinusoidal voltage between terminals 5 and 6, instead of the phase opposition voltages $V_{a_{11}}$ and $V_{a_{13}}$. In this case, voltage V_s -at the center position of core 8- has a known amplitude value that differs from zero (for example, equal to half that of the energizing voltage). With respect to the previously described embodiment, this alternative does not present substantial differences, apart from the phase of output voltage V_o , that does not enable to immediately distinguish displacements in one or in the other sense with respect to the central position of core 8.

The transducer T' shown in figures 3, 4 and 5 includes first and second primary windings 21 and 23 connected in series at a connection point 29, first and second secondary windings 22 and 24, five terminals 31, 32, 33, 34 and 35 and a magnetic core 28 that can perform translation displacements with respect to windings 21-24.

In the configuration shown in figure 3, transducer T' is substantially similar to transducer T of figure 1. In fact, in this configuration, terminal 33 (that ends at connection point 29) and terminal 35 are short circuited, for example by means of a wire 36. The voltage generators 11 and 13 of the conditioning unit C , shown in figure 1, are connected to terminals 32 and 34, while output voltage V_o - substantially identical to the one attained with transducer T - is detected at the ends of load impedance 15 between terminal 31 and ground 12.

In the configuration shown in figure 4, secondary windings 22 and 24, ending at terminals 31 and 35, are not connected to external units and thus are insulated. By providing in this configuration, too, a connection between voltage generators 11 and 13 and terminals 32 and 34, it is possible to attain, by utilizing a suitable setting resistor 27, an output voltage V_o' -at the ends of a load impedance 15' between terminal 33 and ground 12- that varies as the position of core 28 changes, according to the

well known functioning principle of a half bridge transducer or HBT.

Furthermore, in the configuration shown in figure 5, terminal 33 is insulated. A sinusoidal voltage generator 11' is connected to terminals 32 and 34 for feeding a primary winding 21+23 that consists of both windings 21 and 23, while an output voltage $V_{o''}$ is detected, by utilizing a suitable setting resistor 30, at the ends of a load impedance 15'' between terminals 31 and 35 (the latter being connected to ground 12). Voltage $V_{o''}$ varies as the position of core 28 changes, according to the well known functioning principle of a linear variable differential transformer or LVDT.

From the concise description of figures 3, 4 and 5, it appears that transducer T' is particularly flexible, since with a single structure it is possible to attain transducers of different types (LVDT, HBT or transducers of the new type described with reference to figure 1), and in each case achieve the type of transducer with the characteristics that best suit the specific application.

It is also to be noted that the setting resistors 27 and 30 are connected, respectively, to terminal 33 (insulated in the configuration of figure 5) and between terminals 31 and 35 (insulated in the configuration of figure 4). This enables to independently set the sensitivity for the HBT configuration (shown in figure 4) and LVDT configuration (shown in figure 5) on the same transducer T' and directly choose the proper configuration in the application phase, without the need of a further setting.

Transducers that include modifications with respect to what is herein schematically illustrated and so far described, for example in connection with the relative phases of the voltages at the ends of the different windings, also fall within the scope of this invention. In particular, by inverting the phase of the secondary windings (2 and 4 shown in figure 1) with respect to that of the primary windings (1 and 3), formula (2) changes to $V_s = (V_1 - V_3)/2$

and, as a consequence, formula (9) changes to $V_o = V_s (1 + 2 \cdot k \cdot N_2/N_1)$. Thus, this alternative choice enables to attain a higher sensitivity.

As previously discussed with reference to the known
5 transducers (of the LVDT or the HBT type), the use of the
linear inductive transducers in measuring and control
devices and apparatuses is quite widespread and varied, and
the comparator shown in the herein mentioned patent US-A-
4,386,467 represents just one of the many possible
10 applications for transducers T and T' according to the
present invention.